PM/94-04
UTS-DFT-94-02

Information and Discrimination from b Quark Production on Z Resonance

D.Comelli, C. Verzegnassi [1]
Dipartimento di Fisica Teorica, Università di Trieste
Strada Costiera, 11 Miramare, I-34014 Trieste,
and INFN, Sezione di Trieste, Italy

F.M. Renard
Physique Mathématique et Théorique,
CNRS-URA 768, Université Montpellier II
F-34095 Montpellier Cedex 5

Abstract

We introduce and define operatively in a model independent way a new "heavy" b-vertex parameter, η_b, that can be derived from the measurement of a special polarization asymmetry for production of b-quarks on Z resonance. We show that the combination of the measurement of η_b with that of a second and previously defined "heavy" b-vertex parameter δ_{bV} can discriminate a number of models of New Physics that remain associated to different "trajectories" in the plane of the variations of the two parameters. This is shown in particular for some popular SUSY and technicolor-type models. In general, this discrimination is possible if a measurement of <u>both</u> parameters is performed.

[1]Work partially supported by NATO.

1 Introduction

In the first four years of running at LEP1, a remarkable experimental effort has allowed to collect a number of events that begins to approach the 10^7 limit, that was once considered as nothing more than an optimistic dream. This is the result of a number of machines's modifications or improvements, whose main features can be found in several recent publications or in the Proceedings of dedicated Workshops .

Meanwhile, on the other side, the theoretical approach to the interpretation of this huge amount of data has also been adapted and improved. In fact, in very recent years it has become clear that, to a certain extent, the comparison of the various results with the Minimal Standard Model (MSM) predictions, and the consequent search of possible signals of New Physics through small deviations due to one-loop effects, can be performed in a rigorously model-independent way. In particular, it has been stressed [1] that the <u>leptonic</u> charged processes can be "read" in terms of two parameters, originally called $\epsilon_{1,3}$ in ref.[1], in a totally unbiased way, that is for models of New Physics that are willing, or able, to modify any of the three classes (self-energies, vertices, boxes) of one-loop radiative effects (in practice, owing to their intrinsic irrelevance for LEP 1 Physics at the starting MSM level, boxes are usually neglected for this kind of search).

The generalization of the previous philosophy to <u>hadron</u> production requires some preliminary choice. In fact, the extra vertex corrections that enter the theoretical expressions are not universal and introduce new unwanted degrees of freedom of both "light" (in practice, massless) and "heavy" quark type. The latter effect is, for the specific case of e^+e^- Physics on Z resonance, entirely due, in the MSM, to that component of the $Zb\bar{b}$ vertex due to the charged would-be Goldstone exchange that behaves as m_t^2 for large top masses, as it has been exhaustively shown in the literature [2]. Since various models of New Physics generally contribute either the light quark and lepton or the heavy quark degrees of freedom but not both, it becomes necessary to develop an appropriate strategy

to perform a satisfactory search of New Physics effects.

A first possible attitude is that of only considering those models that would <u>not</u> contribute the lepton and light quark vertices. Then, one only has to add to the "canonical" quantities $\epsilon_{1,3}$ one extra parameter . For the latter, an operational definition should now be provided. The original proposal [3], [4], to which we shall stick in this paper, was to define the vertex correction δ_{bV} from the ratio of the $Zb\bar{b}$ and $Zs\bar{s}$ partial widths i.e.

$$\frac{\Gamma_b}{\Gamma_s} \equiv 1 + \delta_{bV} \tag{1}$$

where the physical b width (we follow in fact the slightly modified version given in ref.[4]) should be taken.

Once the definition eq.(1) is chosen, a systematic analysis of all LEP 1 data that includes both leptonic and hadronic channels can be performed in terms of three parameters e.g. ϵ_1, ϵ_3, δ_{bV} or $\Delta\rho$, Δ_{3Q}, δ_{bV} in the notation of ref.[4], for the previously selected set of models of New Physics. This was proposed in ref.[4] and also in another series of papers [5], where an essentially similar $Zb\bar{b}$ vertex parameter was introduced (and defined ϵ_b). Without entering the details of the methods, it should be stressed that the parameter δ_{bV} as defined in eq.(1) is operationally connected to the experimentally measured ratio $R_b = \frac{\Gamma_b}{\Gamma_h}$ by the relation (valid in the considered class of models)

$$\frac{\Gamma_b}{\Gamma_h} \equiv R_b = \frac{13}{59}(1 + \frac{46}{59}\delta_{bV} - \frac{23}{59}(\delta_1 - \delta_2) + \frac{2}{65}\Delta\kappa' + 0.1\frac{\alpha_s(M_Z^2)}{\pi} + \text{“}negligible\text{''}) \tag{2}$$

Here $\Delta\kappa'$ is a radiative correction entirely fixed by the measurements at LEP1 (SLC) of the effective angle $s^2_{EFF}(M_Z^2)$ (which can be identified for practical purposes with each of the existing popular definitions [6])

$$s^2_{EFF}(M_Z^2) = s^2(1 + \Delta\kappa') \quad s^2 \simeq 0.231 \tag{3}$$

and the weight of $\alpha_s(M_Z^2)$ is practically irrelevant. The parameters $\delta_{1,2}$ are certain combinations of leptonic and <u>light</u> quark vertices, whose (small) numerical value can be exactly

computed in the MSM; their definition has been given in a previous paper [7], to whose notations we shall stick. Thus, if New Physics does not affect the light fermion vertices, R_b can provide the unbiased value of δ_{bV}, to be compared with the MSM prediction.

In fact, an overall analysis of data is more elaborated and includes other variables as well. The full details can be found in refs.[4] and [5]; the point that we want to stress here is that, after the most recent LEP1 communicated data [8], this type of investigation leads to the conclusion that ϵ_1, ϵ_3, (or $\Delta\rho$, Δ_{3Q} in the notation of ref.[4]) are now perfectly consistent with the MSM predictions. This means that the small discrepancy that might have been present in the previous determinations of ϵ_3 (Δ_{3Q}) has now been (almost) completely washed out. On the contrary, the possibility of a <u>small</u> deviation is still allowed in the heavy vertex parameter δ_{bV}, since one has now [9]:

$$\delta_{bV} = (-12 \pm 10)10^{-3} \tag{4}$$

and the MSM tolerance region (corresponding to the last bound $m_t \geq 113$ GeV [10]) is

$$\delta_{bV}^{MSM} \leq -0.016 \tag{5}$$

One possible question that becomes relevant at this stage is whether the assumption that the light fermion vertices remain unaffected has some experimental support. To answer this question one should identify (at least) one quantity that is only reacting to such kind of New Physics effect. In fact, this "light vertex indicator" has been proposed in ref.[7] as a certain combination of hadronic and leptonic widths and of $s^2_{EFF}(M^2_Z)$, and defined D. At one loop, it is only affected by a certain combination of light fermion vertices parameters (different from that entering R_b eq.(4)). For that combination, the experimental data show a very good agreement with the MSM predictions, as fully discussed in ref.[7].

If one believes that a small discrepancy is still present in R_b eq.(2), two attitudes become possible. One is that of addressing the full responsability to the heavy b vertex parameter δ_{bV}. The other one is that of thinking that an effect of the light vertex type

could modify the combination entering R_b (with δ_{bV} unaffected), but not that contained in D. Although a priori no possibility should be discarded, we feel that the second choice appears somehow unnatural. Therefore, we shall first concentrate on the more plausible solution, in which New Physics only affects δ_{bV} as a direct consequence of the fact that the b quark is, for a certain type of effects, to be considered as a member of a "heavy" doublet.

In terms of shifts in the (conventionally defined) vector and axial vector $Zb\bar{b}$ couplings, the effect of New Physics on δ_{bV} can be parametrized as

$$\delta_{bV}^{NP} = -\frac{4}{1+b^2}[b\ \delta g_{Vb}^{H} + \delta g_{Ab}^{H}] \tag{6}$$

where

$$b = 1 - \frac{4}{3}s^2 \tag{7}$$

and s^2 is defined by eq.(3). The subscript "H" denotes the fact that we are now considering "heavy" quark type of effects.

For the purposes of our search, it would be extremely useful to define and to measure a certain experimental quantity where a different combination of shifts in g_{Vb}, g_{Ab} enters. In fact, such a quantity exists and has been proposed a few years ago [11]. It was defined as the "longitudinally polarized forward-backward $b\bar{b}$ asymmetry" and usually called A_b

$$A_b = \frac{\sigma(e_L^- \to b_F) - \sigma(e_R^- \to b_F) - \sigma(e_L^- \to b_B) + \sigma(e_R^- \to b_B)}{\sigma(e_L^- \to b_F) + \sigma(e_R^- \to b_F) + \sigma(e_L^- \to b_B) + \sigma(e_R^- \to b_B)} \tag{8}$$

and, as one sees, it requires the availability of longitudinally polarized electron beams. The remarkable feature of A_b is that of only depending on the couplings of Z to b, as it was stressed in Ref.[11] . This explains the great potential interest of its measurement, that will be performed in a very near future at SLC if the very encouraging trend of recent progress in the machine performance is (hopefully) going to continue [12], and might also be performed in a not too far future at LEP if a phase with polarized beams became

operative [13]. If this were the case, an extremely fruitful combination with the results on R_b obtained by unpolarized measurements at LEP1 would become possible, which could allow to draw unexpected conclusions on this fascinating and still existing possibility of small MSM failures.

This short paper is dedicated to the study and to the exploitation of the possible theoretical consequences of a combined determination of R_b and A_b. In Section 2, we shall very briefly recall the needed definitions and the relevant theoretical expressions, In Section 3, an investigation of the possible <u>combined</u> effects on the two heavy vertex measurable combinations of some models of New Physics will be performed, showing that there would be distinct "trajectories" in the $(\delta R_b, \delta A_b)$ plane in correspondence to different models, and also a brief discussion of some "unnatural" possibility of light vertex-type effects will be given, before drawing the final conclusions. A short Appendix will be devoted to the derivation of some mass relationships in one of the considered models, where one extra U(1) is involved.

2 Definition of the second heavy quark vertex parameter

An immediate and natural way of defining a new heavy b vertex parameter is to follow the philosophy that led to eq.(1) in the case of δ_{bV} and to introduce the quantity η_b as

$$A_b = A_s(1+\eta_b) \tag{9}$$

i.e. as the ratio of the longitudinal polarization forward-backward asymmetries for b and s-type quarks. The asymmetry A_s (which corresponds mathematically to that of practically massless b quarks) can be written in a form similar to that of eq.(2) :

$$A_s = 0.703(1 - 0.158(\Delta\kappa' + \delta'_s) - \Delta_{QCD}\frac{\alpha_s}{\pi} + \text{``}\textit{negligible}\text{''}) \tag{10}$$

in which δ'_s is a vertex correction defined in [7] and Δ_{QCD} is a QCD factor of order one. With this choice, one can easily see that the expression of η_b becomes :

$$\eta_b = -\frac{2(1-b^2)}{b(1+b^2)}[\delta g^H_{Vb} - b\,\delta g^H_{Ab}] \tag{11}$$

The shifts $\delta g^H_{Vb,Ab}$ in eq.(11) take into account in the MSM the effect of the would-be Goldstone exchange in the $Zb\bar{b}$ vertex and also QCD effects due to the not negligible b-mass, whose complete calculation has been given elsewhere [14] and that are, as such, supposedly known. The important feature is that, <u>in the MSM</u> (but not a priori in the models of New Physics that we shall consider) the effect on η_b of the charged would-be Goldstone boson (that is proportional to m_t^2 in δ_{bV}) is practically negligible, owing to the fact that it gives the same contributions to δg_{Vb} and to δg_{Ab}, that are nearly cancelling in the combination of eq.(11). Thus, in the MSM prediction for A_b, the "heavy" b vertex component $\sim m_t^2$ can be ignored and the relevant expression does only contain universal self-energies and light vertices (and known QCD corrections). Obviously, this property is a priori no longer verified as soon as one considers models of New Physics, for which the relative role of η_b could be much more relevant or fundamental.

To make the previous statement more illustrative, it is convenient to reexpress the shifts of δ_{bV} and η_b, rather than in the (g_V, g_A) basis, in that provided by the (conventionally defined) (g_L, g_R) parameters. In that case, one can write:

$$\delta_{bV} = -\frac{4(1+b)}{(1+b^2)}\left[\delta g^H_{bL} - \frac{(1-b)}{(1+b)}\delta g^H_{bR}\right] \tag{12}$$

$$\eta_b = -\frac{2(1-b)}{b}\left[\delta g^H_{bR} + \frac{(1-b)}{(1+b)}\delta g^H_{bL}\right] \tag{13}$$

As one sees, in the (L,R) basis the two shifts are orthogonal, which means that effects that would not contribute one observable will be revealed by the other one, and conversely.

To the previous remarks one can still add a property of η_b that is a direct consequence of our chosen definition eq.(9). In fact, if one eliminates δg^H_{bL} in eq.(12), one obtains:

$$\eta_b = -\frac{2(1-b)}{b}\left[\frac{2(1+b^2)}{(1+b^2)}\delta g^H_{bR} - \frac{(1-b)(1+b^2)}{4(1+b)^2}\delta_{bV}\right] \tag{14}$$

and, to a very good approximation, this becomes:

$$\eta_b = -\left[\delta g^H_{bR} - \frac{1}{25}\delta_{bV}\right] \tag{15}$$

showing that, once δ_{bV} is experimentally known, the measurement of η_b fixes unambiguously the pure right-handed contributions from various models to the "heavy " $Zb\bar{b}$ vertex.

After these preliminary definitions, all the necessary ingredients to formulate an unbiased search of New Physics effects in the "heavy" quark vertex sector are at our disposal. One only has to take eqs.(12), (13), insert a "New Physics" apex to both the right and the left-hand side, and choose a set of interesting models to be examined. This will be done in the forthcoming Section 3.

3 Survey of models affecting the heavy b vertex

The simplest known example of a model that contributes the heavy b vertex is that with just one extra Higgs doublet. In this case both the charged and the neutral higgses will have to be considered. The charged contribution can be decomposed into two terms. The first one essentially reproduces that of the MSM (i.e.$\sim$ δg_{bL}) with the same kind of m_t dependence (weighted by a factor $\sim \cos\theta^2\beta$ where $\tan\beta$ is the ratio of the two VEV's); the second one is proportional to the product of m_b^2 and $\tan^2\beta$. As such, it can only be relevant for very large values of $\tan\beta \approx m_t/m_b$. Since it only modifies the right-handed $Zb\bar{b}$ coupling, it will generate a suppressed effect in δ_{bV} (again, of the same sign as that of the MSM). More interestingly, it will also be able to affect η_b. The neutral higgses sector

is described by a larger set of parameters, and is therefore more model dependent than the charged one. In general, it will affect both δg_{bL} and δg_{bR} with terms proportional to m_b^2 and will consequently be only relevant if some enhancement factor can be adjusted. In particular, this can be achieved when the value of $\tan\beta$ becomes very large. In this case, its contribution to δ_{bV} can be of opposite sign to that of the MSM [15].

These features of the simplest model with one extra Higgs doublet remain essentially unchanged if one embeds it in a supersymmetric picture, with the additional constraints between the various couplings and the existence of other types of contributions to be taken into account. This has been done in great detail in a number of previous papers [16] for the specific case of the so-called "Minimal" Supersymmetric Standard Model (MSSM) [17] for both small and large values of $\tan\beta$. The results of all analyses indicate that in some cases the effects of the Higgs sector and of the genuine "soft" supersymmetric sector can add up constructively, leading to possible effects of a few percent that should be visible at future measurements of δ_{bV}, η_b.

Among the configurations examined in ref.[16], that corresponding to large $\tan\beta$ values was considered as a particularly interesting one. The main motivation is that, while for small $\tan\beta$ values the model essentially contributes δg_{bL} but not δg_{bR}, in the large $\tan\beta$ case it can affect both δg_{bL} and δg_{bR}. As a consequence of this, two independent experimental tests would become available which would give rise to some implications. In particular, one would be able to draw certain "trajectories " in the (η_b, δ_{bV}) plane that would correspond to, or identify, a certain model and could be experimentally "seen ", at least in a certain part of the plane.

In the analyses of ref. [16], the contribution of the Higgs sector was calculated using the SUSY mass relationships valid at tree level in the MSSM. Since it has become known [18] that these relationships are appreciably modified at one loop, one might be interested in evaluating the eventual modification of the relevant trajectories (that are certain functions

of the various higgses masses). Also, one might consider the effect of adding an extra neutral Higgs to the model since this seems to be a reasonable extension of the "minimal" picture.

In this paper, we have examined the two possibilities and considered as a tool model with one extra Higgs the so called η model [19], whose mass relationships at tree level, that have been already examined in the literature [20], show several interesting differences with those of the MSSM. The results of our calculation will be only shown for the Higgs sector and for the related trajectories. The remaining contributions should be identical with those computed in ref.[16] in the MSSM case. For the η model, a separate calculation of non Higgs effects should be performed. We believe, though, that the already existing limits on the mass of the extra Z of this model, $M_{Z'} > 500$ GeV [7], pushing the involved soft masses to large values, limit somehow in this model their potential effect (that should not differ drastically, in any case, from the corresponding MSSM one).

The relevant diagrams containing the various Higgses contributions are shown in Fig.1; from these one derives compact expressions that have been already provided in the literature. Here we shall follow the notations of Ref.[15] that, in the large $\tan\beta$ configuration chosen by us produce the relatively simple formulae:

$$\delta g_{bR}^{H} = \frac{\alpha}{16\pi s^2}\frac{m_b^2\tan^2\beta}{M_W^2}[(1-\frac{4}{3}s^2)\ \rho_3[m_t, M_{H^+}, m_t, M_Z]$$

$$-m_t^2\ C_0[m_t, M_{H^+}, m_t, M_Z] + (s^2-c^2)\ \rho_4[M_{H^+}, m_t, M_{H^+}, M_Z]$$

$$+(-1/2+1/3s^2)\ (\rho_3[m_b, M_A, m_b, M_Z] + \rho_3[m_b, M_h, m_b, M_Z])$$

$$-\frac{1}{2}\rho_4[M_h, m_b, M_A, M_Z] - \frac{1}{2}\rho_4[M_A, m_b, M_h, M_Z]] \qquad (16)$$

$$\delta g_{bL}^{H} = \frac{\alpha}{16\pi s^2}\frac{m_b^2 \tan^2\beta}{M_W^2}[+1/3s^2(\rho_3[m_b, M_A, m_b, M_Z] + \rho_3[m_b, M_h, m_b, M_Z])$$

$$-\frac{1}{2}\rho_4[M_h, m_b, M_A, M_Z] - \frac{1}{2}\rho_4[M_A, m_b, M_h, M_Z]] \tag{17}$$

Here $\rho_{3,4}[m_1, m_2, m_3, M_Z]$ and $C_0[m_1, m_2, m_3, M_Z]$ are the functions introduced in the appendix of ref.[15]. The masses that appear in the previous expressions are those of the charged Higgs (M_{H^+}) , of the CP-odd neutral Higgs (M_A) and of that CP-even neutral Higgs (M_h) whose mass is nearly degenerate with M_A in the MSSM and in the η model.Starting from the given expressions, one only has to insert, at a certain level of accuracy, the mass relationships of the various models that are, in general, not the same. In particular, the famous tree-level formulae of the MSSM and the corresponding ones of the η model [20] can be substantially different. For example, one finds in the first case the equality :

$$M_{H^+}^2 = M_A^2 + M_W^2 \tag{18}$$

whilst in the second model one has:

$$M_{H^+}^2 = M_A^2 + M_W^2 \left[1 - \frac{2\lambda^2}{g^2}\right] \tag{19}$$

where λ is a free parameter. Also, one finds a bound for the lightest neutral in the MSSM, that becomes sensibly larger in the other case [20]. At one loop,extra not negligible differences can arise in both models, which could in principle give rise to observable effects.

Motivated by the previous argument, we have calculated eqs.(16), (17) inserting the one-loop mass relationships of the two models.For the MSSM, these are known and can be found in the literature [18]. For the η model,in the chosen configuration, they are given in the short Appendix. The numerical values of δ_{bV} and η_b are shown in the following Figures. They will depend on m_t (from the charged sector), on $m_b \tan\beta$ (from both

sectors) and on <u>one</u> residual neutral mass chosen to be $M_A \approx M_h$ .The value of M_{H^+} remains fixed by the choice of the configuration, as shown in Appendix , for the MSSM.In the case of the η model,for which extra parameters exist, we have chosen the situation that optimizes the effect and thus the related figures are actally showing the maximal deviations that the model can produce. All the numerical results are given for $m_b = 5$ GeV, $\tan\beta = 70$, following the approach of Ref.[16].

To get a qualitative feeling of the differences obtained by using the modified mass relationships, we show in Figs.2, 3 the trajectories corresponding to the MSSM with mass constraints at tree level, eq.(18), and at one loop. One sees that one effect is that of "smoothening" the m_t dependence, particularly in the heavy mass region,say, between 150 GeV and 200 GeV (intermediate and upper lines)(this is a consequence of the fact that in the charged Higgs contribution this dependence is now weakened in the relevant ratio between the top and the Higgs masses). Also, one notices a systematic (small) decrease in η_b, compensated by a corresponding (small) increase in δ_{bV}.

In fact, the compensation between η_b and δ_{bV} is quite general, in the sense that for small M_A values the full (positive) effect is on the second parameter, while for large M_A only the first one is modified. This is related to the fact that η_b is dominated by right-handed effects, that are peculiar of the charged Higgs contribution whose decoupling is slower than that of the neutral ones (that give the important effect on δ_{bV}).

If we accept the experimental available indications [8] that seem to prefer <u>positive</u> (or, at least, not too negative) δ_{bV} shifts, we conclude that the most relevant part of the Higgs sector trajectory of this model lies in the positive η_b region of the plane (with the exception of the fraction that would correspond to substantial δ_{bV} effects (larger than,say, two percent) i.e. to very small M_A values , where the shift on η_b could be negative). Since the same feature seems to be valid for the remaining genuinely supersymmetric contributions of the model [16], we conclude that the simultaneous observation of (small)

positive deviations in either δ_{bV} or η_b, or possibly in both ,could be interpreted as the experimental evidence for this model in the considered region of its parameter space. This would require a precision of the two measurements of the order of a relative one percent, although in certain favourable cases the shifts could be larger than that, particularly if the effects from the Higgs and the genuine SUSY sector added in a substantial way as they seem to be willing to do.

The case of the η model is illustrated in Fig.4, only showing the situation where the mass constraints are used at one loop. As one sees, the results for the Higgs sector are very similar to those of the previous example,with a small general increase of η_b and practically no change in δ_{bV}. Since we expect that other contributions are somehow depressed in this case , we would conclude that the trajectories of this model are qualitatively similar to those of the MSSM (with possibly smaller overall effects); in other words, the presence of one more neutral scalar does not affect the trajectory in this case. Whether this is a general feature of SUSY models with one extra (singlet) scalar remains to be investigated; we postpone the discussion of this point to a next forthcoming paper.

It can be interesting to remark that in the "orthogonal" case of Technicolor-type modifications of the MSM, the associated trajectories would be completely different for a wide class of models.This can be deduced from the analysis presented in reference [21] where the contributions to δ_{bV} were computed. In fact, for a class of "walking technicolor" cases the effect on δ_{bV} was negative and of purely left-handed type, leading in any case to negative corrections to η_b as one can easily verify from the defining eqs.(12), (13). The exception to this statement would be represented by a class of special models where fermion masses are due to the presence and mixing of technibaryons [22],that produce positive shifts in δ_{bV}. But for these models, the shift in η_b can be written to a good approximation, using again eqs.(12), (13) as follows:

$$\eta_b \simeq \delta_{bV} \frac{1 - 5c^2}{5(5 + c^2)} \tag{20}$$

where $c^2 = \sin^2\alpha / \sin^2\beta'$ and α, β' are the two mixing angles of the model.Varying this ratio from zero to infinity fixes η_b in a region between ,practically, zero and -δ_{bV} as shown in the next Fig.5. Thus, the observation of two small effects of opposite sign with a negative η_b would provide a rather peculiar evidence for this special model.

To conclude our investigation, we have considered the (less attractive, in our opinion) possibility that the origin of small discrepancies in $\frac{\delta R_b}{R_b}$ and $\frac{\delta A_b}{A_b}$ is due to effects of light-fermion type. Firstly, we have considered the class of models with one extra Z' of E_6 origin that has been often considered in the literature [19]. For these models, strong experimental constraints on the mixing angle exist [7] that limit its modulus to be less than, say, one percent. Using this extreme value as the tolerated limit for every single model (which is somehow optimistic) we obtain the effects shown in Fig.6. As expected, the possible effects of this kind are always below the one percent level and are spread in the ($\frac{\delta R_b}{R_b}$, $\frac{\delta A_b}{A_b}$) plane. In other words, the existing limits on the mixing angle seem to prevent interesting effects from these models. Note, accidentally, that the contribution coming from the η model (that would belong in the chosen configuration of large $\tan\beta$ values to positive mixing angles) goes in the opposite direction to that of the Higgs sector,which represents a negative feature of the model. We have repeated our analysis for an extra Z' predicted by Left-Right symmetry models and for higher vector bosons predicted by various types of different models,in particular compositeness inspired models (Y, Y_L, Z^*) [24] and alternative symmetry breaking models (Z_V) [25] . As in the first case, the limits imposed by precision tests in the light fermion sector prevent from getting large effect on R_b and A_b as one can see in Fig.6.

We can summarize the results of this preliminary investigation as follows. Assuming as a realistic goal a final experimental accuracy on the measurements of both A_b and R_b of a relative one percent, the best chances of providing visible signals seem to belong to models of New Physics that can affect the "heavy" b-vertex component. Among these,

we have seen that those of SUSY type are associated to trajectories in the plane of the variations of δ_{bV} and η_b that differ substantially from those of technicolor type. We stress the fact that this differentiation is made possible by the combined measurements of the two observables; for instance, the discovery of a positive effect in δ_{bV} could not discriminate the models of Figs.2, 3, 4 from that of Fig.5. Should this effect (that is apparently not disallowed by the existing data) survive in the future, the role of a high precision measurement of η_b would become, least to say, fundamental.

Before concluding this paper we would like to make a rather speculative remark concerning the possibility that a positive shift of R_b is observed with no effect on A_b. From a purely technical point of view, it might be possible to explain this effect in a picture where the MSM calculation is still valid, but where the effective axial coupling of Z to the top is slightly decreased. In fact, in the large m_t limit, the dominant contribution to δg_{bL} can be expressed in the form:

$$\delta g_{bL} \simeq \frac{\alpha}{8\pi s^2}\frac{m_t^2}{M_W^2} g_{t,A} \tag{21}$$

and values of $g_{t,A}$ slighty smaller than one-half (with no effect on the corresponding b-vertex) could provide this possible deviation, thus motivating searches of reasonable models where the axial "form factors" of heavy quarks can be possibly modified [23].

Acknowlegements

One of us (C.V.) acknowledges some useful discussions with B.W.Lynn and H.Schwarz during a stay at UCLA in summer 1993.

Appendix

In this Appendix we give the expressions of the relevant radiative corrections (R.C.) to eq.(18) in the MSSM and to eq.(19) in the η model. The Higgs sector of the MSSM at tree level is described by two parameters, $\tan\beta$ and M_A; when we include the radiative corrections all the parameters which describe the spectrum of the theory enter in the mass formulae. The most important contributions to the R.C. come from the stop-sbottom sector, so we must fix: the soft squark masses ($m_{\tilde{t}_{L,R}} = m_{\tilde{b}_{L,R}} = m_{\tilde{q}} \simeq 1$ TeV); the trilinear SUSY breaking parameters ($A_t = A_b = 100$ GeV) ; the SUSY $H_1 H_2$ coupling μ and of course the top mass. In the large $\tan\beta$ limit the one loop mass relationships read [18]:

$$M_{H^+}^2 = M_A^2 + M_W^2 + \Delta M_{H^+}^2 \tag{22}$$

where

$$\begin{aligned}\Delta M_{H^+}^2 = {} & \frac{3g^2}{32\pi^2 M_W^2}[2m_t^2 m_b^2 \tan^2\beta - M_W^2(m_t^2 + m_b^2\tan^2\beta) \\ & + \frac{2}{3}M_W^4] \log\frac{m_{\tilde{q}}^2}{m_t^2} + \frac{3g^2}{96\pi^2}[m_t^2\left(\frac{\mu^2 - 2A_t^2)}{m_{\tilde{q}}^2}\right) \\ & + m_b^2\tan^2\beta\left(\frac{\mu^2 - 2A_b^2)}{m_{\tilde{q}}^2}\right)] + \frac{3g^2}{64\pi^2}M_W^2[\frac{m_t^2 m_b^2\tan^2\beta}{M_W^4}\left(\frac{A_t + A_b}{m_{\tilde{q}}^2}\right)^2 \\ & - \frac{\mu^2}{m_{\tilde{q}}^2}\left(\frac{m_t^2 + m_b^2\tan^2\beta}{M_W^2}\right)^2] - \frac{3g^2 m_t^2 m_b^2\tan^2\beta}{192\pi^2 M_W^2}\left(\frac{A_t A_b - \mu^2}{m_{\tilde{q}}^2}\right)^2\end{aligned} \tag{23}$$

The radiatively corrected mass M_h of the CP-even neutral Higgs which runs into the loop of Fig.1 is always nearly equal to M_A .

In the η model the tree level Higgs sector is defined by 4 parameters: $\tan\beta, M_A, x, \lambda$. The new parameter x is the VEV of the extra complex Higgs field N and fixes the scale of the breaking of the extra U(1) gauge group, so naturally $x \gg v_1, v_2$. In this large

x limit the Higgs sector, that is described by 3 CP-even,1 CP-odd and 1 charged-state, effectively reduces, at the M_Z scale, to that of the MSSM with the following identifications: $\mu = \lambda x, m_3^2 = \lambda A_\lambda x$ (m_3^2 is the soft SUSY breaking term of the operators $H_1 H_2$ in the MSSM, A_λ is the trilinear soft term which multiplies the product $N H_1 H_2$ in the potential). When R.C. are evaluated, besides the parameters of the MSSM there is another Yukawa coupling h_E of the exotic quark sector ($m_{\tilde{E}} = m_{\tilde{q}},\ A_E = A_t$) So finally the extra new parameters are λ, x and h_E. We fix x via the mass of the extra Z' boson: $M_{Z'} = 25/18 g_1^2 x^2$ =0(1 TeV). The exotic Yukawa coupling gives very little contributions (some GeV) to the "standard" Higgs sector and can be safely fixed to 1. The Higgs spectrum is at the contrary very sensitive to the λ parameter: this strong dependence is exibited by the charged Higgs sector (see eq.(19)) and by the ligthest CP-even mass. As shown in ref.[20] (for values of $M_A < M_{Z'}$) the ligthest Higgs mass (M_l) is a convex parabola in the λ^2- M_l plain. The imposition of the experimental bound $M_l \geq 60$ GeV gives a very strong upper limit on λ (tipically $\lambda < 0.4$); therefore the difference between the charged Higgs mass (for fixed M_A) in the two models cannot be arbitrarily large. The mass M_h is again nearly equal to M_A. So, the only effective difference between the η model and the MSSM, in this region of the space parameters, is contained in the relation $M_{H^+} - M_A$:

$$M_{H^+}^2 = M_A^2 + M_W^2 (1 - \frac{2\lambda^2}{g^2}) + \Delta M_{H^+}^2 + \Delta' M_{H^+}^2 \tag{24}$$

where $\Delta M_{H^+}^2$ is the same as in eq.(20) with the suitable identifications and $\Delta' M_{H^+}^2$ is the small contribution of the exotic sector:

$$\Delta' M_{H^+}^2 = -\frac{3}{8\pi^2} M_W^2 \frac{\lambda^2}{g^2} h_E^2 \left[\log \frac{m_{\tilde{q}}^2 + m_E^2}{M_Z^2} - \frac{1}{6} \frac{A_E^2 m_E^2}{m_{\tilde{q}}^2 + m_E^2} \right] \tag{25}$$

In general when $\lambda \to 0$ we have the same relationships $M_{H^+} - M_A$ as in the MSSM and the trajectories in the plane (δ_{bV}, η_b) are the same. What we have shown in Fig.4 are the trajectories with the maximum value of λ such that the neutral Higgs sector is beyond

the present experimental bound.

References

[1] G.Altarelli and R.Barbieri, Phys. Lett. **B253**, 161 (1990) .

[2] A.Akhundov, D.Bardin and T.Riemann, Nucl. Phys. **B276**, 1 (1986) ; W. Beenakker and W.Hollik, Z. Phys. **C40**, 141 (1988) ; B.W.Lynn and R.G.Stuart, Phys. Lett. **B252**, 676 (1990) ; J.Bernabeu, A.Pich and A. Santamaria, Nucl. Phys. **B363**, 326 (1991) .

[3] A.Blondel, A.Djouadi and C. Verzegnassi, Phys. Lett. **B293**, 253 (1992) .

[4] A.Blondel and C. Verzegnassi, Phys. Lett. **B311**, 346 (1993) .

[5] G.Altarelli, R.Barbieri, F.Caravaglios, Phys. Lett. **B314**, 357 (1993) .

[6] D.C.Kennedy and B.W.Lynn, Nucl. Phys. **B253**, 216 (1985) ; A.Sirlin Phys. Lett. **B232**, 971 (1989) ; M.Consoli and W.Hollik in "Physics at LEP I", G.Altarelli, R.Kleiss, C.Verzegnassi eds. CERN 89-09 (1989).

[7] J.Layssac, F.M. Renard and C. Verzegnassi preprint PM/93-13 UTS-DFT-93-13 (to appear on Phys. Rev.D).

[8] We use the data comunicated by the various LEP collaborations at the EPS Conference, Marseille, July 1993.

[9] A.Blondel and C. Verzegnassi, seminar presented at the 1993 Marseille Conference, to appear on those proceedings.

[10] The CDF Collaboration, A.Barbaro-Galtieri, Proceedings of the EPS Conference on High Energy Physics, Marseille, France (1993).

[11] A.Blondel, B.W.Lynn, F.M. Renard and C. Verzegnassi, Nucl. Phys. **B304**, 438 (1988) .

[12] For a recent review of the machine's status, see e.g. C.Prescott, SLAC-PUB-66355, September 1993.

[13] For a recent review on the subjet, see e.g. A. Blondel CERN-93-125.

[14] A.Djouadi,J.H.Kuhn and P.Zerwas, Z. Phys. **C46**, 411 (1990) .

[15] A.Denner, R.J.Guth, W.Hollik and J.H. Kuhn, Z. Phys. **C51**, 695 (1991) .

[16] A.Djouadi, J.L.Kneur and G.Moultaka, Phys. Lett. **B242**, 265 (1990) ; A.Djouadi, G.Girardi, W.Hollik, F.M.Renard and C.Verzegnassi Nucl. Phys. **B349**, 48 (1991) ; M.Boulware and D.Finnel, Phys. Rev. **D44**, 2054 (1991) ; C.Sheng Li, J.Min Yang, B. Quan Hu and Y. Sheng Wei CQU-TH-92-17, Dec.5, 1992.

[17] L.E.Ibanez Phys. Lett. **B118**, 73 (1982) ; Nucl. Phys. **B218**, 514 (1983) ; R.Barbieri, S.Ferrara and C.Savoy, Phys. Lett. **B119**, 343 (1982) ; P.Nath, A. Arnowitt and A. Chamseddine, Phys. Lett. **B49**, 970 (1982) .

[18] J.F.Gunion and A. Turski, Phys. Rev. **D40**, 2325 (1989) ; M.A.Diaz and H.E.Haber, Phys. Rev. **D45**, 4246 (1992) .

[19] For a full discussion of this model (and similar ones) see e.g. L.Hewett and T.G. Rizzo, Phys. Rep. **C183**, 193 (1989) .

[20] H.E.Haber and M.Sher, Phys. Rev. **D35**, 2206 (1987) ; M.Drees, Phys. Rev. **D35**, 2910 (1987) ; D.Comelli, C.Verzegnassi, Phys. Lett. **B303**, 277 (1992) .

[21] R.S. Chivukula, S.B.Selipsky and E.H. Simmons, Phys. Rev. Lett. **69**, 575 (1992) .

[22] D.B.Kaplan, Nucl. Phys. **B365**, 259 (1991) .

[23] The possibility that the axial form factors of the constituent quarks are modified in a rather different context has been already discussed in several papers. See e.g. S.Peris,

Phys. Lett. **B268**, 415 (1991) , S.Weinberg, Phys. Rev. Lett. **67**, 3473 (1991) , E. de Rafael and S.Peris, Phys. Lett. **B309**, 389 (1993) . The effects of anomalous top quark couplings on precision electroweak measurements have been also considered by R.D.Peccei and X.Zhang, Nucl. Phys. **B337**, 269 (1990) , R.D.Peccei, S.Peris and X.Zhang, Nucl. Phys. **B349**, 305 (1991) , M.Frigeni and R.Rattazzi, Phys. Lett. **B269**, 412 (1991) .

[24] M.Kuroda, D.Schildknecht and K.H.Schwarzer, Nucl. Phys. **B261**, 432 (1985) .

[25] R.Casalbuoni, S.De Curtis, D.Dominici and R.Gatto, Nucl. Phys. **B282**, 234 (1987) ; J.L.Kneur and D.Schildknecht, Nucl. Phys. **B357**, 357 (1991) ; J.L.Kneur, M.Kuroda and D.Schildknecht, Phys. Lett. **B262**, 93 (1991) .

Figure Captions

Fig.1 : Self energy and vertex corrections to the $Zb\bar{b}$ vertex

Fig. 2 : Plot in the (δ_{bV}, η_b) plane of the corrections (in percent) in the MSSM case with the relationships $M_{H^+} - M_A$ at tree level (see eq. (18)). There are 16 point for each "curve" ,each one corresponding to a given value of M_A,in particular (starting from the right to the left): M_A= 40, 45, 50, 55, 60, 65, 70, 75, 80, 90, 100, 120, 140, 160, 180, 200 GeV. The upper line corresponds to m_t=200 GeV, the intermediate one to m_t= 150 GeV and the lowest one to m_t= 110 GeV.

Fig. 3 : The same as before for the MSSM but with the mass relationships at one loop (see eq.(22)).

Fig. 4 : The same as before but for the η model and with the mass relationships at one loop (see eq.(24)).

Fig. 5 : The set of allowed trajectories for the Kaplan model discussed in ref.[21,22] at variable ratio c^2 of the two mixing angles.

Fig. 6 : Maximal allowed $Z - Z'$ mixing effects in the $(\frac{\delta R_b}{R_b}, \frac{\delta A_b}{A_b})$ plane, from E_6 based models with $-1 \leq \cos(\beta) \leq +1$ (dashed), from L-R symmetry based models with $\sqrt{\frac{2}{3}} \leq \alpha_{LR} \leq \sqrt{2}$ (full), in both cases with $|\theta_M| = 0.01$. We have also indicated the trajectories or small domains allowed for various alternative models of higher vector bosons (Y, Y_L, Z^*, Z_V) taking into account the constraints established in ref.[7].